



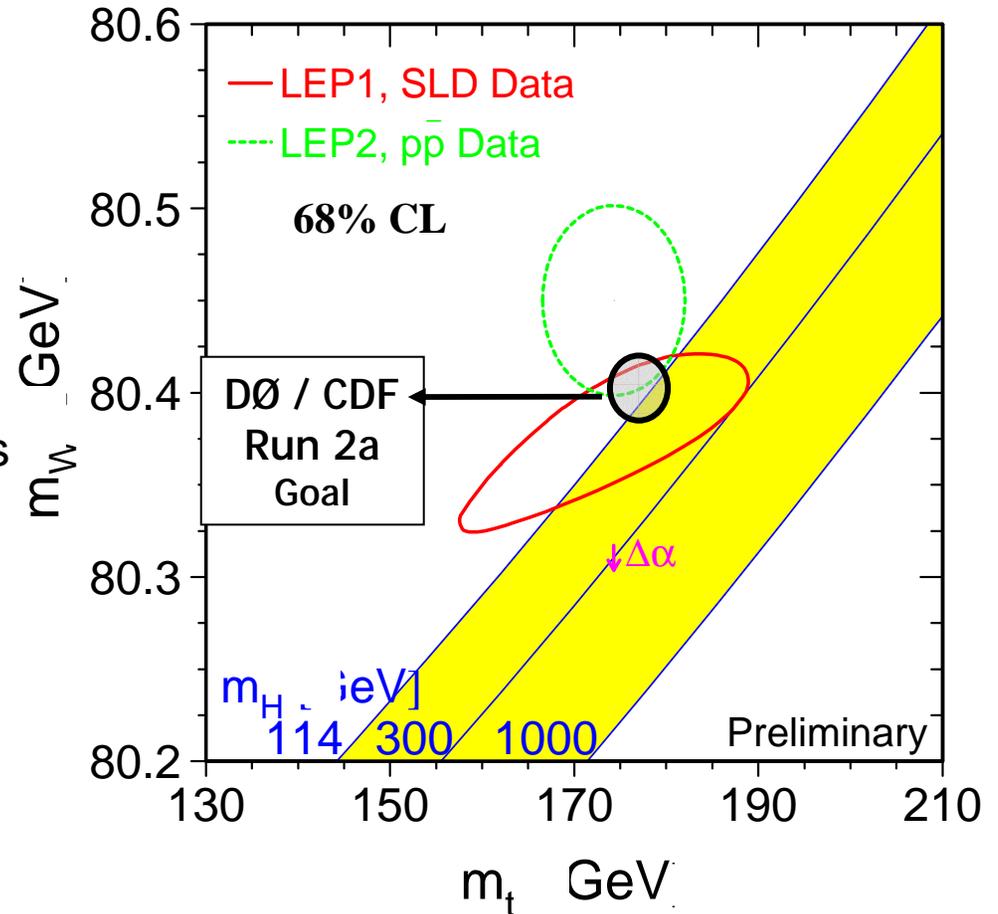
Recent Results on Top Quark and Electroweak Physics from CDF



B. Winer

Brian L. Winer
Ohio State University
CDF Experiment

- Performance of the Tevatron/CDF
- Electroweak Analyses
 - W/Z Production Cross Sections
 - Forward-Backward Asym.
- Top Physics
 - tt Production Cross Section
 - Mass Analysis
 - Other Top Properties
 - Search for Single Top
- Summary





Run II CDF Detector

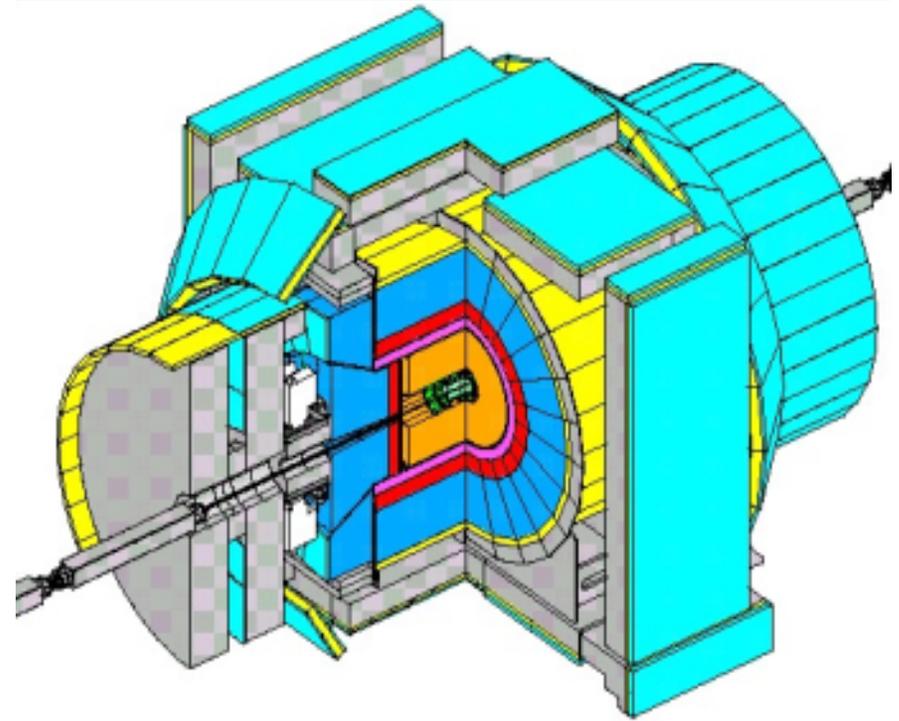


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Upgraded Components

- Tracking
 - Silicon
 - 707K channels
 - Full Coverage of luminous region
 - Radial coverage from 1.35-28cm
 - Central Outer Tracker
 - 30k sense wires, 44-132 cm
 - 96 dE/dx samples/track
- Time of Flight
- Expanded Muon Coverage
- Endplug Calorimeter
- Trigger (pipelined)
 - Drift Chamber Tracks @ L1
 - Silicon Tracks @ L2
- Fully Digital DAQ (132 ns)

Collider Detector at Fermilab II



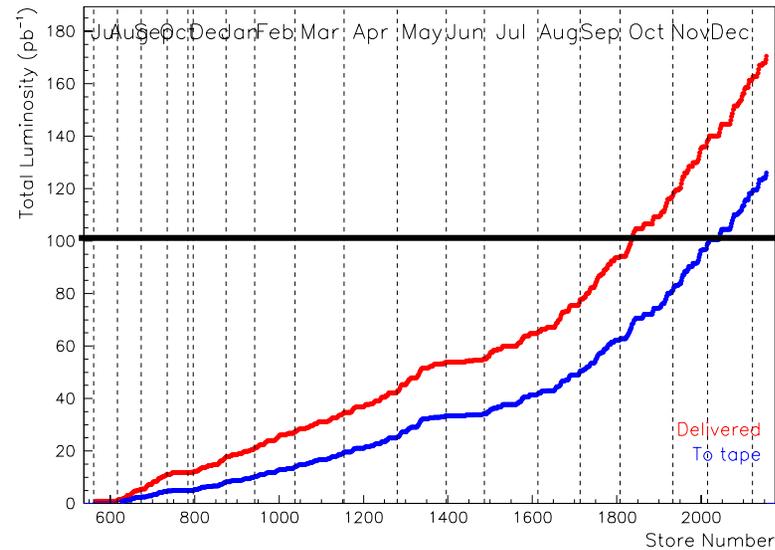


Performance

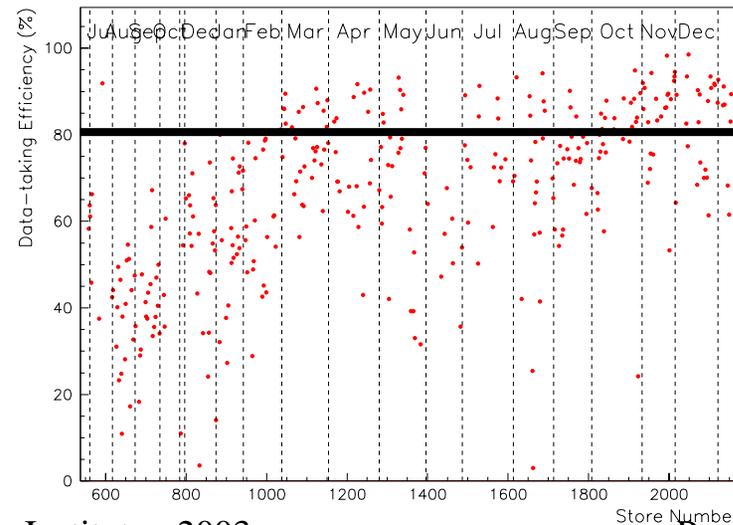


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- Upgrades for Run II:
 - ❑ Main Injector (150 GeV proton storage ring) replaces Main Ring.
 - ❑ Shorter interbunch spacing (396 ns)
 - ❑ Beam Energy: CM 1.96 TeV
- Luminosity:
 - ❑ Peak: $3.8 \times 10^{31} \text{ cm}^{-2}\text{s}^{-1}$
 - ❑ $\sim 170 \text{ pb}^{-1}$ delivered
 - ❑ $\sim 120 \text{ pb}^{-1}$ recorded
 - Subset Analyzed.
- Future Goals:
 - ❑ 250 pb^{-1} by Summer 2003
 - ❑ 2000 pb^{-1} for Run IIa



100pb⁻¹



80%



Overview of Electroweak Measurements



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- First Priority: Reestablish baseline measurements

- $W \rightarrow l\nu$ Cross Sections
- Ratio of W/Z Cross Sections
- Forward/Backward Asym.

- W Charge Asym.

- Constraints on PDFs

- W Mass Measurement

- Dominated by Systematics

- Diboson Production

- $WW, WZ, W\gamma$

- Triboson Couplings

- Search for New Physics

Expected Event Yields 2 fb^{-1}

Sample	Run I	Run IIa
$W \rightarrow l\nu$	77k	2300k
$Z \rightarrow ll$	10k	202k
WV ($W \rightarrow l\nu, V=W,\gamma,Z$)	90	1800
ZV ($Z \rightarrow ll, V=W,\gamma,Z$)	30	500
$t\bar{t}$ (mass sample, ≥ 1 b-tag)	20	800



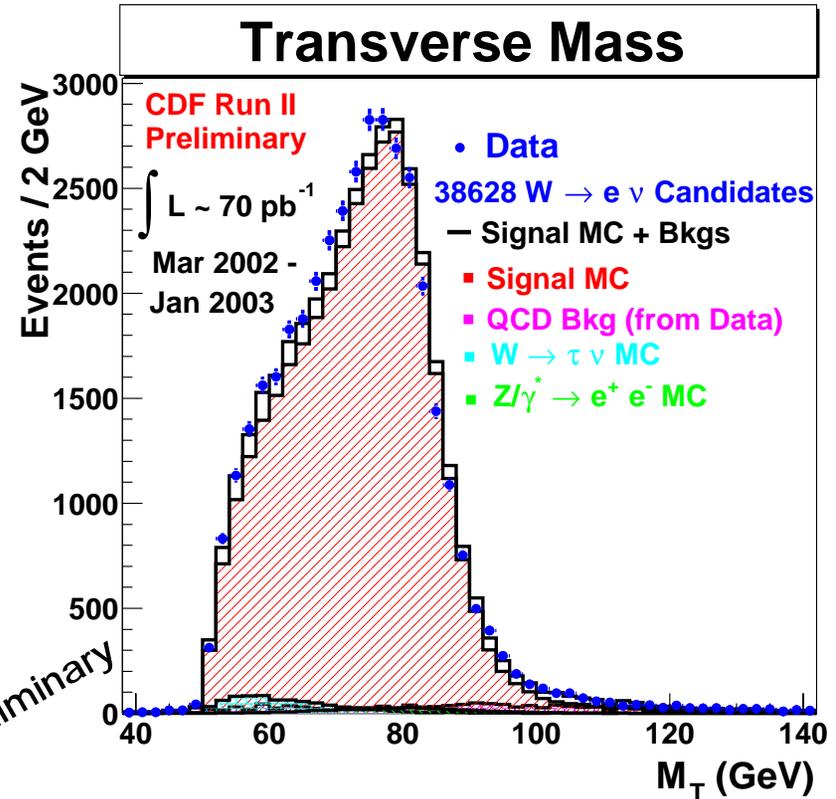
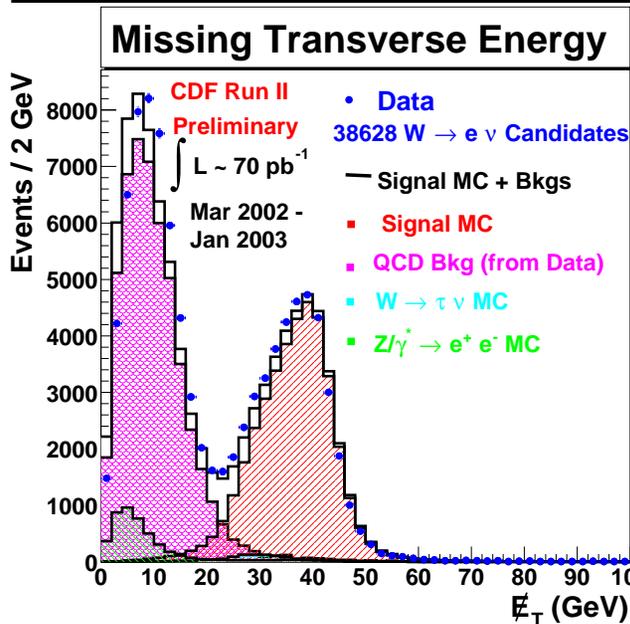
$\sigma^*B(W \rightarrow e\nu)$

Number of Candidates:

- **38,628 in 70.1 pb⁻¹**

Background (~6%):

- QCD: **1344 ± 82 ± 672**
- Z → ee: **768 ± 22**
- W → τν: **344 ± 17**



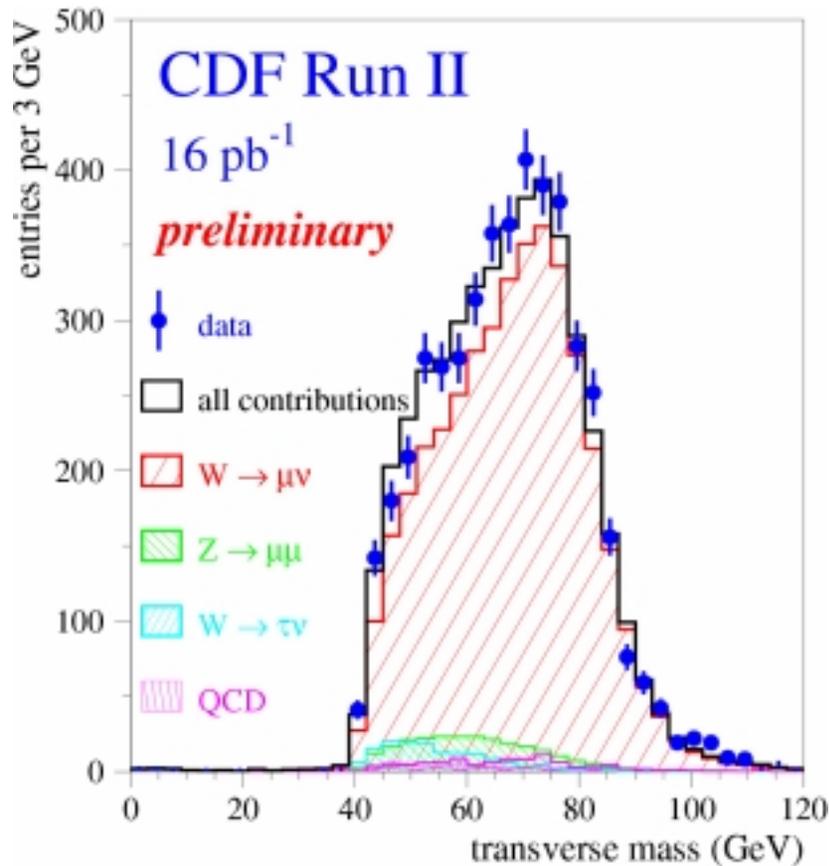
$$\sigma^*B(W \rightarrow e\nu) = 2.69 \pm 0.01_{\text{stat}} \pm 0.09_{\text{syst}} \pm 0.27_{\text{lum}} \text{ nb}$$



$\sigma^*B(W \rightarrow \mu\nu)$



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Number of Candidates:

- 4561 in 16 pb⁻¹

Background (12.5%) :

- QCD: 104 ± 53
- cosmics: 73 ± 30
- Z → μμ: 247 ± 13
- W → τν: 145 ± 10

To be updated to ~70 pb⁻¹ soon...

$$\sigma^*B(W \rightarrow \mu\nu) = 2.70 \pm 0.04_{\text{stat}} \pm 0.19_{\text{syst}} \pm 0.27_{\text{lum}} \text{ nb}$$



$\sigma * B(Z \rightarrow ee)$



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Luminosity:

70.7 pb⁻¹

Observed Events:

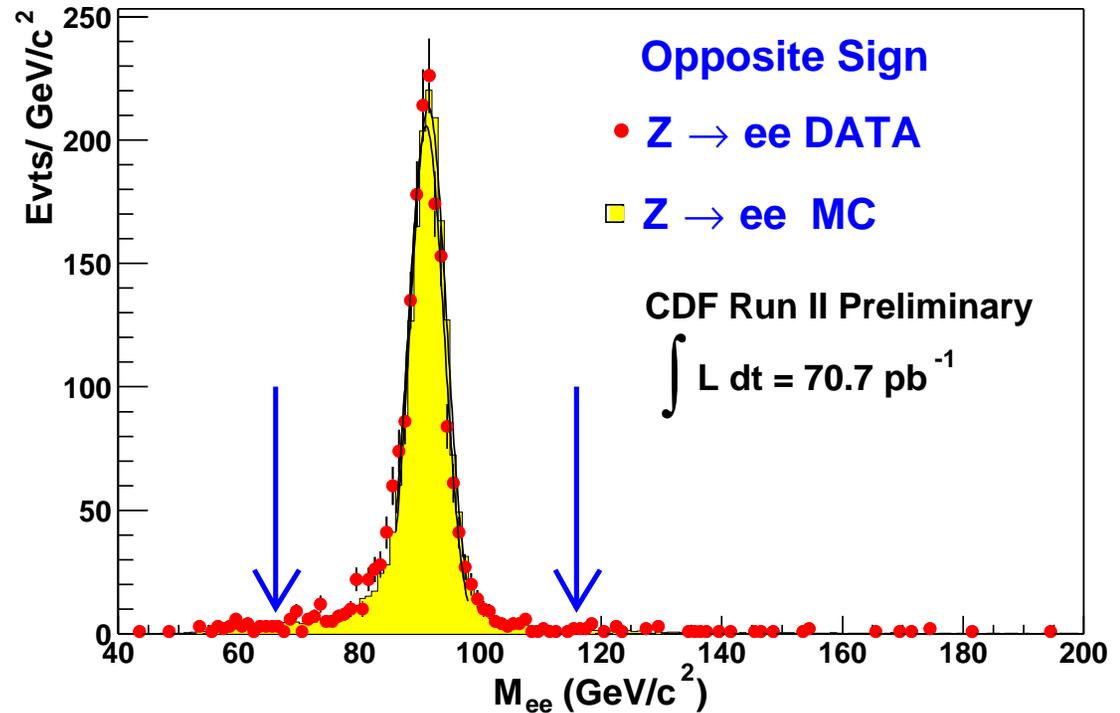
1830 Events

Background (~0.5%)

9.7 ± 5.3

NNLO Prediction:

250.2 pb



$$\sigma_Z \cdot B(Z \rightarrow ee) =$$

$$269.0 \pm 6.3(stat) \pm 15.1(sys) \pm 26.9(lum) pb$$



Ratio of Cross Sections



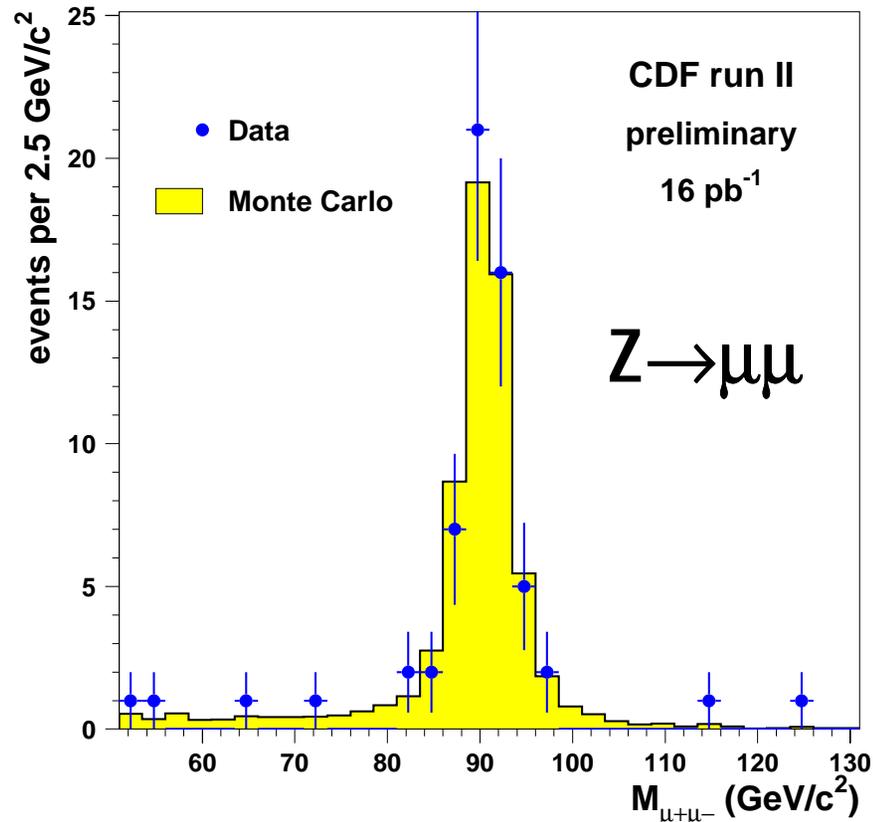
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$$R_\ell = \frac{\sigma(pp \rightarrow W)\Gamma(Z)\Gamma(W \rightarrow \ell\nu)}{\sigma(pp \rightarrow Z)\Gamma(W)\Gamma(Z \rightarrow \ell\ell)} = \frac{N_W \epsilon_Z A_Z}{N_Z \epsilon_W A_W}$$

$$R_\mu = \sigma(W \rightarrow \mu\nu) / \sigma(Z \rightarrow \mu\mu) =$$

$$13.66 \pm 1.94_{\text{stat}} \pm 1.12_{\text{syst}}$$

CDF Run 2 Preliminary (16 pb⁻¹)



$$R_e = \sigma(W \rightarrow e\nu) / \sigma(Z \rightarrow ee) =$$

$$9.93 \pm 0.24_{\text{stat}} \pm 0.58_{\text{syst}}$$

CDF Run 2 Preliminary (70.7 pb⁻¹)

$$\text{Run Ia: } R_e = 10.96 \pm 0.29_{\text{stat}} \pm 0.33_{\text{syst}}$$

$$\text{Extracted } \Gamma(W) \text{ GeV} =$$

$$2.30 \pm 0.06_{\text{stat}} \pm 0.11_{\text{syst}}$$

CDF Run 2 Preliminary (70.7 pb⁻¹)

PDG: 2.118 ± 0.042



W Boson Mass Measurement



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- W Mass Measurement obtained by fitting the M_T^W distribution.
- Systematic Errors are the dominant limitation
 - Scale and Resolution of the lepton energy scale down with lum. by using $Z \rightarrow ll$.
 - P_T^v depends on average number of interactions.

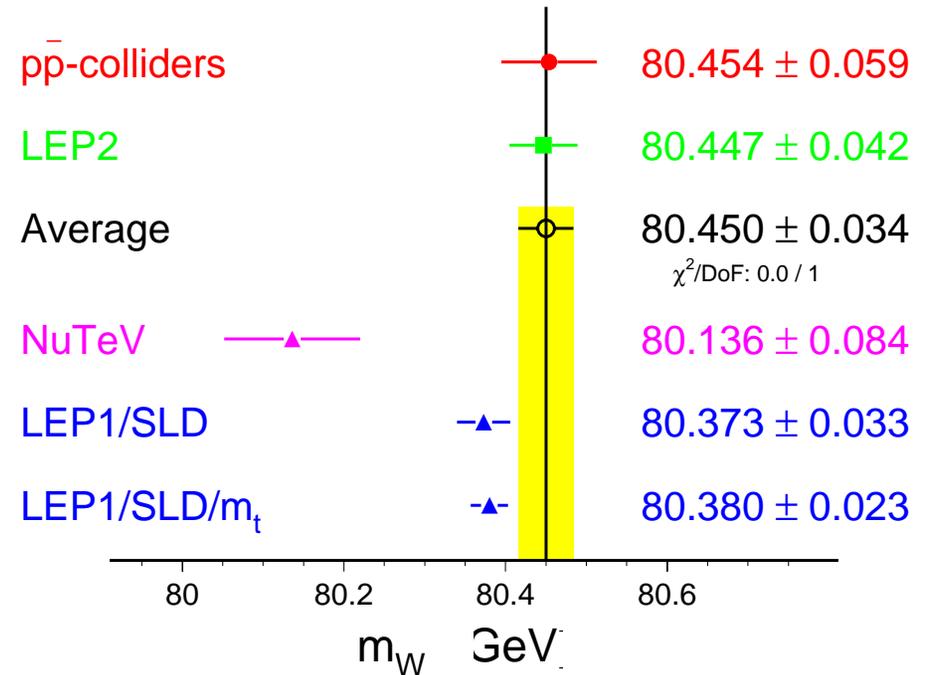
Run II Expectation (2 fb^{-1}):

$$\delta M_W \sim 40 \text{ MeV}/c^2$$

Combined Tevatron Measurement

$$\delta M_W \sim 30 \text{ MeV}/c^2$$

W-Boson Mass [GeV]



World Average Expectation:

$$\delta M_W \sim 15\text{-}20 \text{ MeV}/c^2$$



Forward Backward Asymmetry (A_{FB})



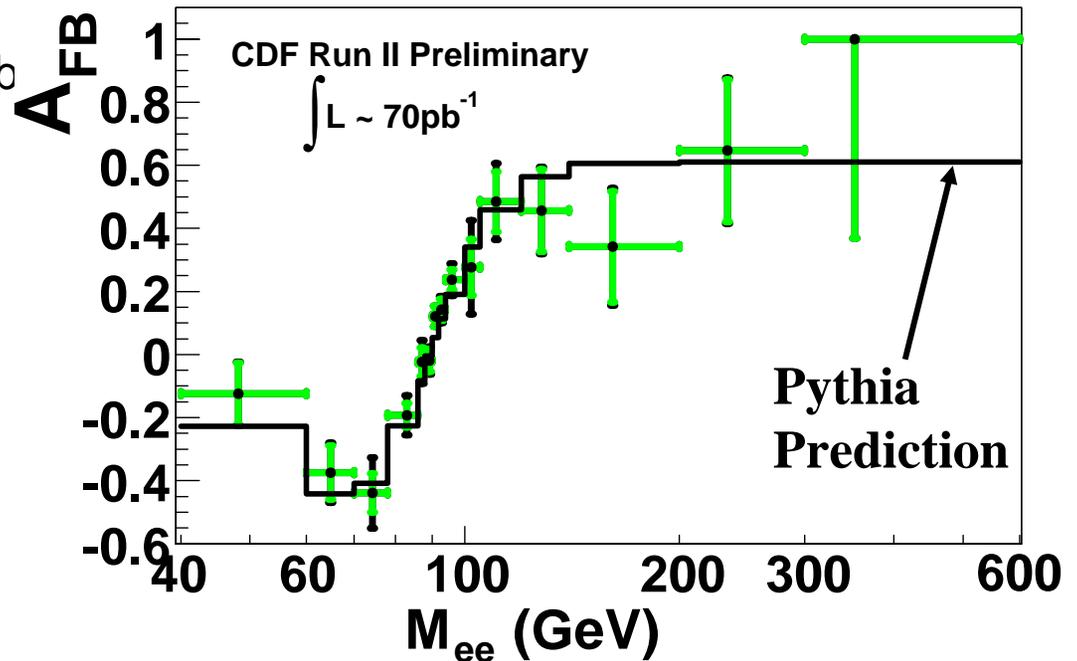
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$$\frac{d\sigma(q\bar{q} \rightarrow Z/\gamma \rightarrow \ell^+\ell^-)}{d\cos\theta} = A(1 + \cos^2\theta) + B\cos\theta$$

$$A_{FB} = \frac{N_F - N_B}{N_F + N_B} = \frac{\sigma(\cos\theta > 0) - \sigma(\cos\theta < 0)}{\sigma(\cos\theta > 0) + \sigma(\cos\theta < 0)} = \frac{3B}{8A}$$

A, B depend on I, Q_q , and $(M_{ll})^2$

- A_{FB} Measurement based on $\sim 70 \text{ pb}^{-1}$ of data
- Direct probe of the relative strengths of the vector and axial-vector couplings
- A_{FB} modified by neutral gauge bosons beyond the SM
- Extract $\sin^2\theta^{\text{eff}}$ from A_{FB}





Top Quark Physics



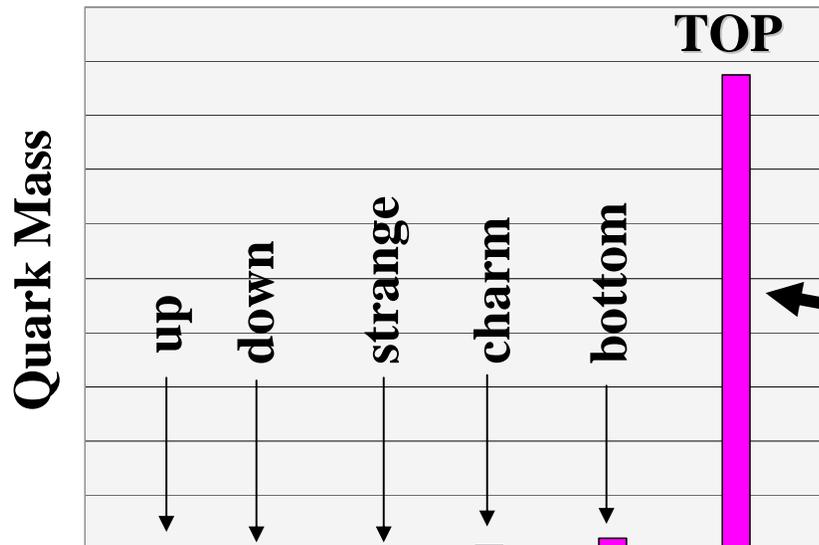
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- Top Quark can only be studied at the Tevatron.
- Run I provided the discovery of the quark but samples were statistically limited
 - 10's of events
- Run II will provide an opportunity to study the top quark in much greater detail.



When Trish discovers Ned works exclusively with top quarks, she will be putty in his hands.

It's Different!



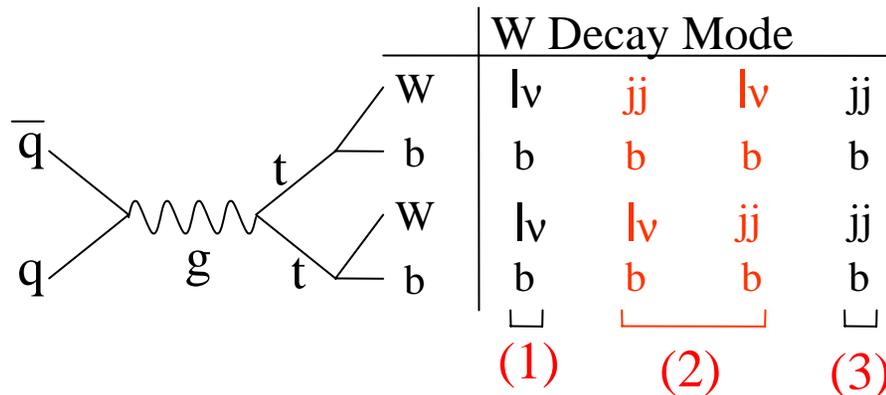


Production and Decay of the Top Quark



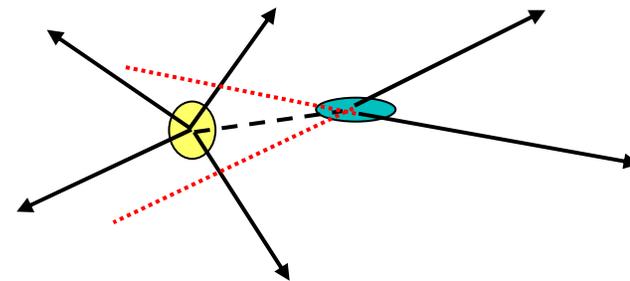
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- At the Tevatron, top quarks are primarily produced in pairs
- Each quark decays $\sim 100\%$ into a W-boson and b-quark. The final state depends on the decay products of the two W bosons in the event.



- (1) **Dilepton** Very small backgrounds, but very small cross section
- (2) **Lepton + Jets** Good cross section and manageable backgrounds
- (3) **All Jets** Huge QCD Background

- Charge lepton (e, μ) from W decay
 - High P_t (>20 GeV/c)
 - Neutrino gives missing energy
- Jets are energetic ($E_t > 15$ GeV)
- Rely heavily on tagging the b-quarks
 - **Soft Lepton Tag** ($b \rightarrow \ell \nu c$)
 - **Secondary Vertex Tag**





Top Quark Overview



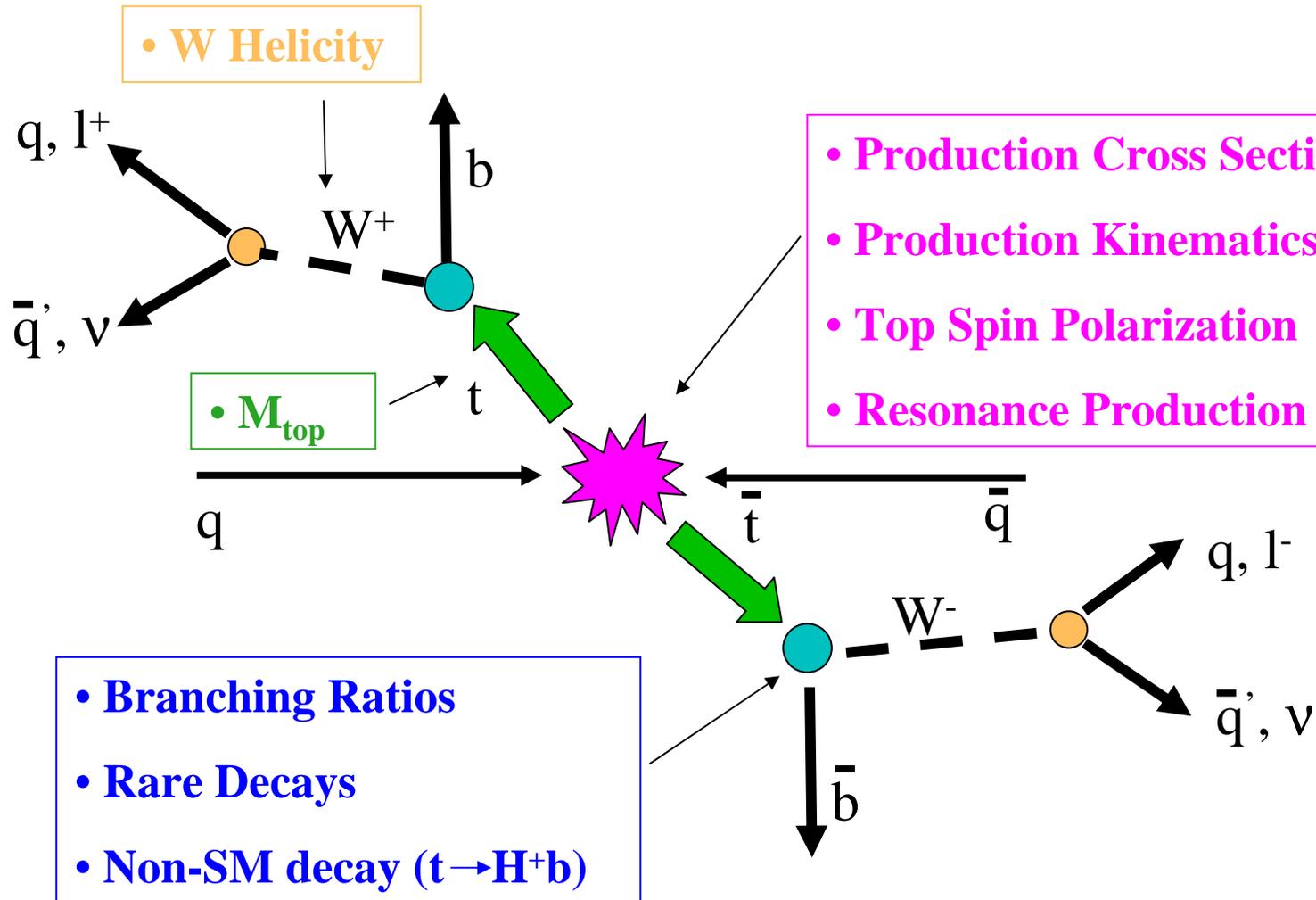
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Decay Channel	Event Yield (2 fb ⁻¹)	
Produced $t\bar{t}$	13,600	525
Dilepton ($e\bar{e}, \mu\bar{\mu}, e\mu$)	160	8
Tau Dileptons ($e\tau, \mu\tau$)	20	-
$e, \mu + \geq 3$ jets	1500	80
$e, \mu + \geq 3$ jets + ≥ 1 b-tag	1000	25
mass sample w/ ≥ 1 b-tag	800	15
mass sample w/ ≥ 2 b-tags	250	5

Approx #'s from Run I and in current 70 pb⁻¹ Run IIA 



Top Physics Subjects





$\sigma_{t\bar{t}}$



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$$\sigma_{t\bar{t}}(\sqrt{s} = 1.96 \text{ TeV}) \approx 1.30 \times \sigma_{t\bar{t}}(\sqrt{s} = 1.8 \text{ TeV})$$

Top Cross Sections

- Measurement of the cross section is primarily a “counting experiment”

$$\sigma(t\bar{t}) = \frac{N_{obs} - N_{bkg}}{A \cdot \int L}$$

- Measure in different decay channels and using different techniques (b-tagging, kin. Fitting, Neural Net)

DØ combined
($m_t = 172 \text{ GeV}/c^2$)

CDF combined
($m_t = 175 \text{ GeV}/c^2$)

DØ L+jets
(topological)

CDF L+jets
(SVX b-tag)

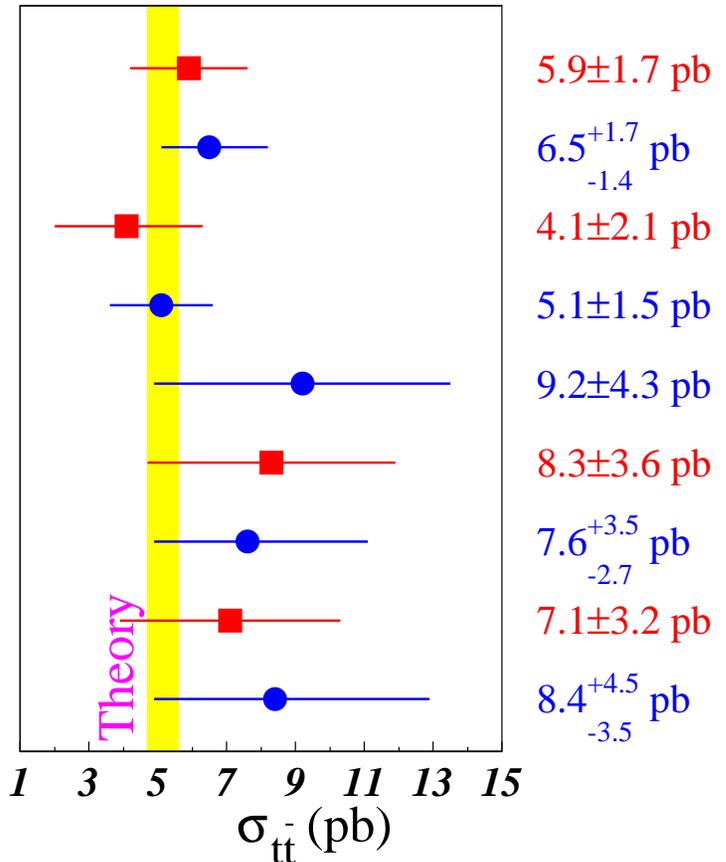
CDF L+jets
(Soft Lepton Tag)

DØ L+jets
(Soft Lepton Tag)

CDF Hadronic

DØ Hadronic

CDF Dilepton



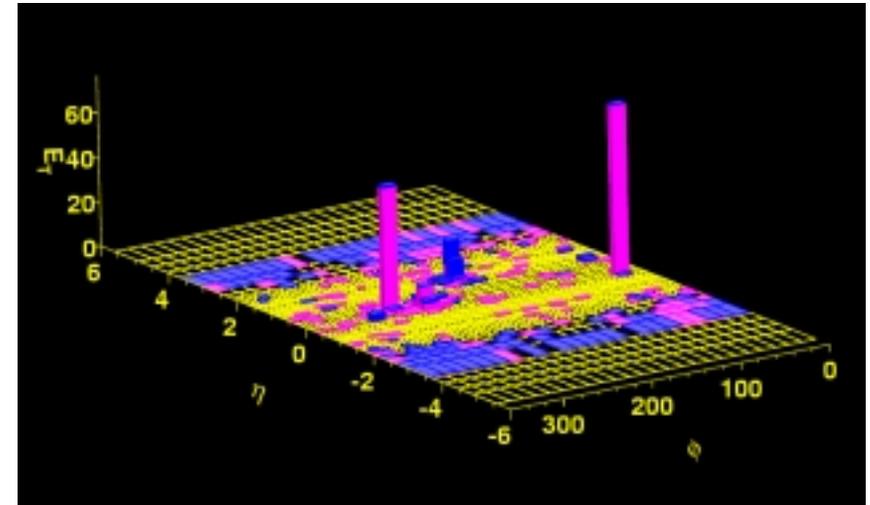
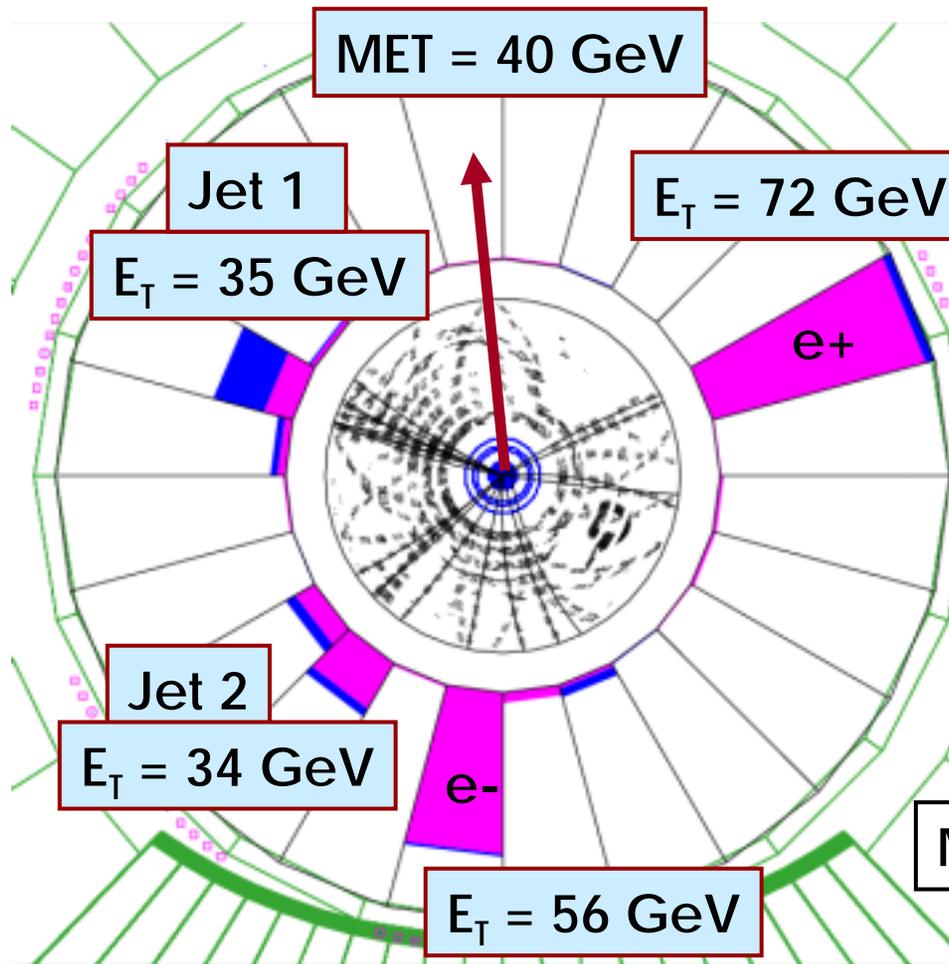
Run I Results ($\sim 100 \text{ pb}^{-1}$)

Run IIa (2 fb^{-1}): $\delta\sigma_{t\bar{t}}/\sigma_{t\bar{t}} \sim 7\%$

Next Week (70 pb^{-1}): $\delta\sigma_{t\bar{t}}/\sigma_{t\bar{t}} \sim 30\%$



Candidate Dilepton Event



CDF Top Dilepton Candidate

$M_{ee} = 118 \text{ GeV}/c^2$ and $H_T = 255 \text{ GeV}$

CDF Run 2 Preliminary

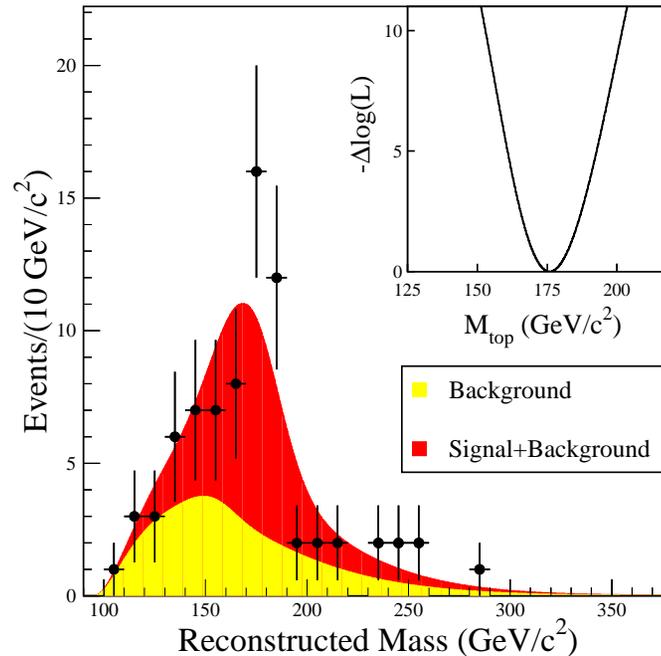


Top Mass Measurement



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- Measure in each Channel:
 - Lepton+Jets
 - Constrained Fitting
 - All Hadronic
 - Constrained Fitting
 - Dilepton
 - “2 Neutrino Problem”
- Improvements for Run IIa
 - Improved b-tagging
 - Double Tags ($N_{\text{exp}} \sim 250$)
 - Jet Energy Scale
 - $Z \rightarrow bb$ control sample
 - Improved Techniques
 - Gluon Radiation Measurement
 - Other good ideas



**CDF:
Run I
Result**

Run I:

CDF: $M_{top} = 176.1 \pm 6.6 \text{ GeV}/c^2$

Tevatron: $M_{top} = 174.3 \pm 5.1 \text{ GeV}/c^2$

Run IIa Exp: $\Delta M_{top} = 2 - 3 \text{ GeV}/c^2$

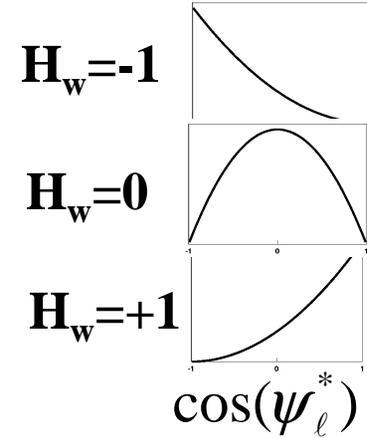
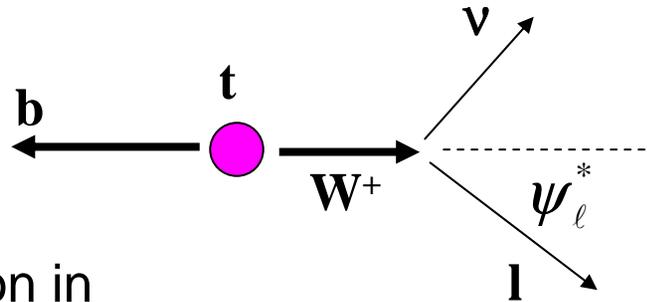


W Helicity: Test for V+A Comp.



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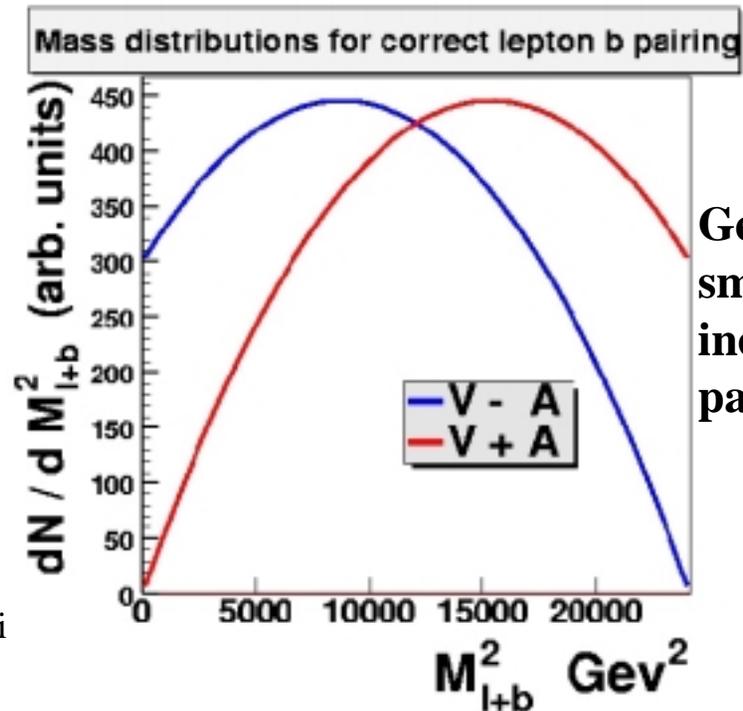
- SM Predicts W Helicity:
 - ~70% Longitudinal
 - ~30% Left-handed (V-A)
- Angle ψ_ℓ^* between the lepton in the W rest-frame and the boost direction from the top rest-frame.
- Use



$$M_{lb}^2 = \frac{1}{2} \cdot (M_{top}^2 - M_W^2) (1 + \cos \psi_\ell^*)$$

which has a dependence on ψ_ℓ^* but is frame independent.

- Fit for the fraction of right-handed (V+A) component



Gets smeared by incorrect pairings



Recent V+A Analysis



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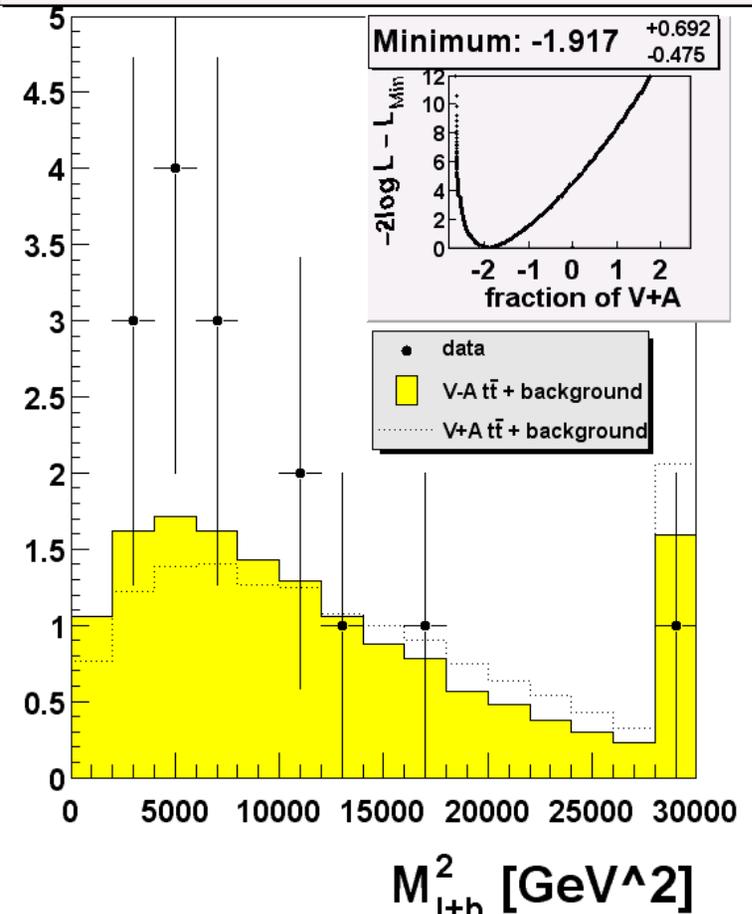
New CDF Run I Result:

(Using $t\bar{t}$ dilepton, and lepton+jets events with 1 and 2 SVX b-tagged jets)

$$f_{V+A} = -0.21^{+0.42}_{-0.25} \pm 0.21$$

Luminosity	Stat Error	Syst Error
109 pb ⁻¹ (run I)	0.59	0.21
500 pb ⁻¹	0.19	0.11 (2000 pb ⁻¹)
1000 pb ⁻¹	0.14	
2000 pb ⁻¹	0.10	

Results of SVX single b-tagged sample



CDF Run I Preliminary



Search for Single Top Quark Production



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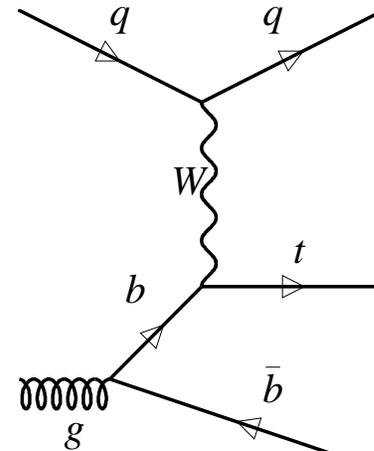
- Predicted by standard model. Direct probe of the strength (V_{tb}) of the electroweak vertex t - W - b . **Background for Higgs events.**

- W -gluon fusion (t-channel):
 - Hard b-jet, W decay products, soft b-jet (usually lost), light q jet
 - $\sigma = 2.88 \pm 0.22$ pb (Stelzer *et al*)

- s-channel W^* :
 - 2 hard b-jets, W decay products
 - $\sigma = 0.88 \pm 0.12$ pb (Smith *et al*)

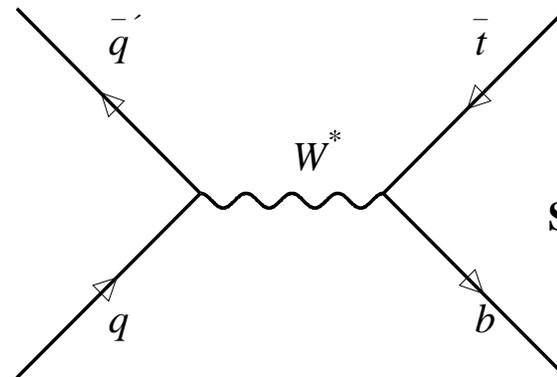
- Backgrounds include: Wbb , Wcc , Wc , mistags, and tt production.

W-gluon fusion process



Signal is $W+b+q$

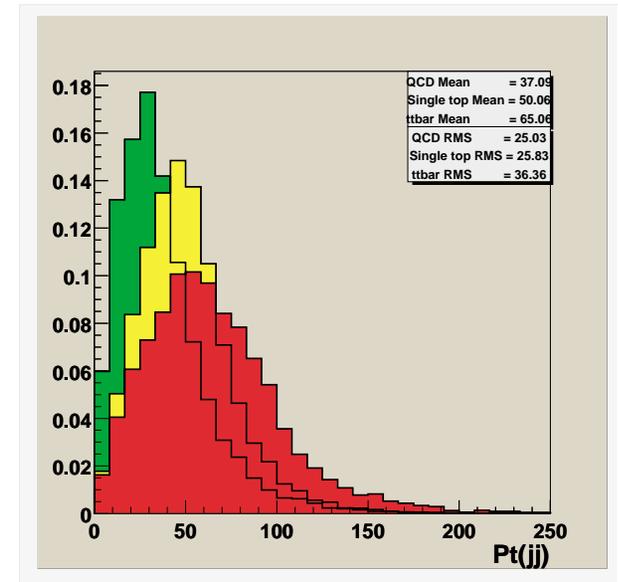
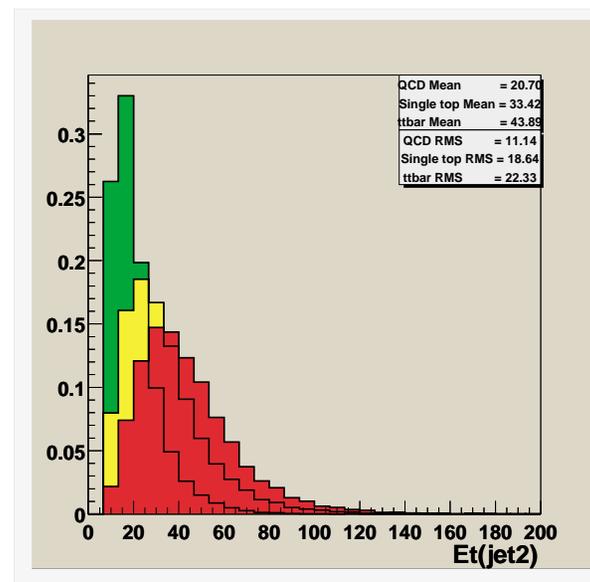
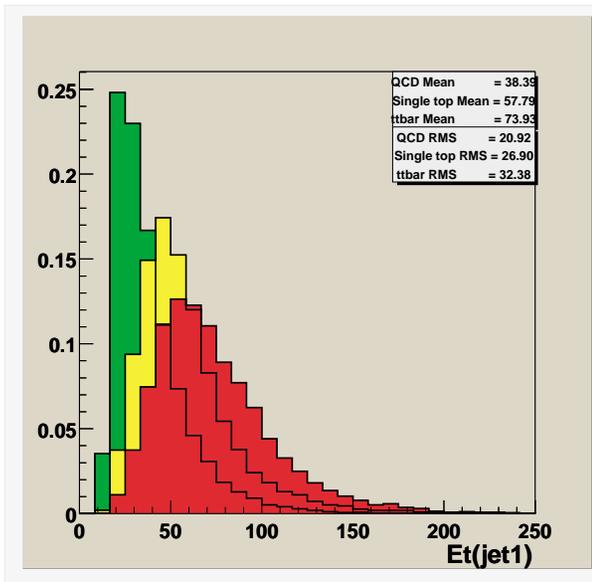
s-channel W^ process*



Signal is $W+b+b$



What Makes Single Top Hard



- non-top background
- $t\bar{t}$ background
- signal

All histograms normalized to unit area for comparison

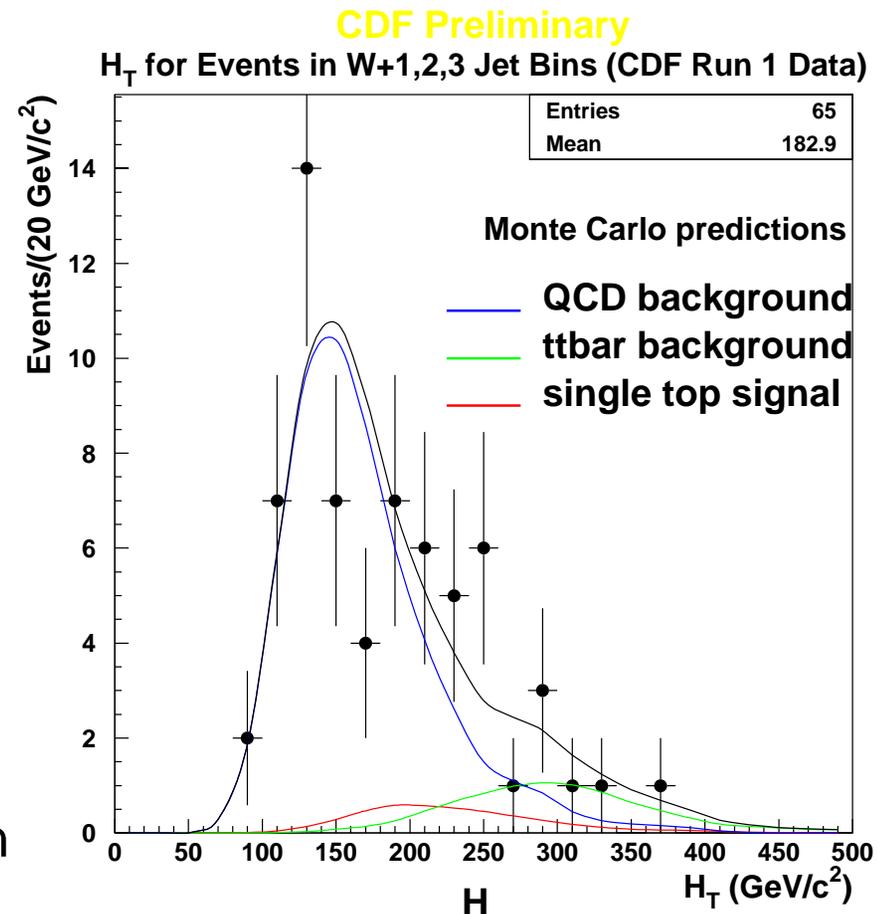


Single Top Searches



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- Search Searches from Run I
 - Fit to H_T Distribution
 - 95%CL $\sigma(Wg+W^*) < 14$ pb
 - Separate Search for Wg and W^* processes:
 - 95%CL $\sigma(Wg) < 13$ pb
 - 95%CL $\sigma(W^*) < 18$ pb
 - Neural Net Search ($Wg+W^*$)
 - 2.5σ excess of events
 - VERY Preliminary
- Run IIa should provide enough data to observe single top production.
- Use Single Top Quark Production to measure $|V_{tb}|$.





Summary of Sensitivities



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Measurement	Est. Uncertainty	Tests
M_t	2-3 GeV/c²	Indirect M_H
$\delta\sigma_{tt}$	7%	QCD Couplings
$\delta[\sigma_{ll}/\sigma_{l+j}]$	12%	Non-SM Decays
$\delta[B(t \rightarrow Wb)/B(t \rightarrow WX)]$	2.8%	“
$\delta[B(t \rightarrow Wb)/B(t \rightarrow Xb)]$	9%	“
$\delta[B(t \rightarrow W_{long})]$	5.5%	Non-SM Coup.
$\delta[B(t \rightarrow W_{V+A})]$	2.7%	
$\delta[\sigma B(Z' \rightarrow t t)]$	~90 fb	Exotics
+ others...		

- Searches:
 - Single Top Production (cross section, Vtb)
 - $X \rightarrow tt$
 - Rare Decays ($t \rightarrow Zc$, $t \rightarrow gc$, $t \rightarrow WZb$, $t \rightarrow WWc$, $t \rightarrow Hc$)



Summary



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- Run IIa is well underway and we are in the process of reestablished some of the basic physics signals
 - W/Z Cross Sections
 - tt Cross Section
- Some of the more complicated analyses will follow
 - Top mass
 - W Mass
- With larger sample (later this year) we will be able to extend our Run I searches for extensions to the standard model
 - Diboson couplings
 - Top Properties
- More results based on the 70 pb^{-1} will be released over the next several weeks.
- By summer we hope to have $\sim 200 \text{ pb}^{-1}$.
- Goal for Run IIa is still 2000 pb^{-1}